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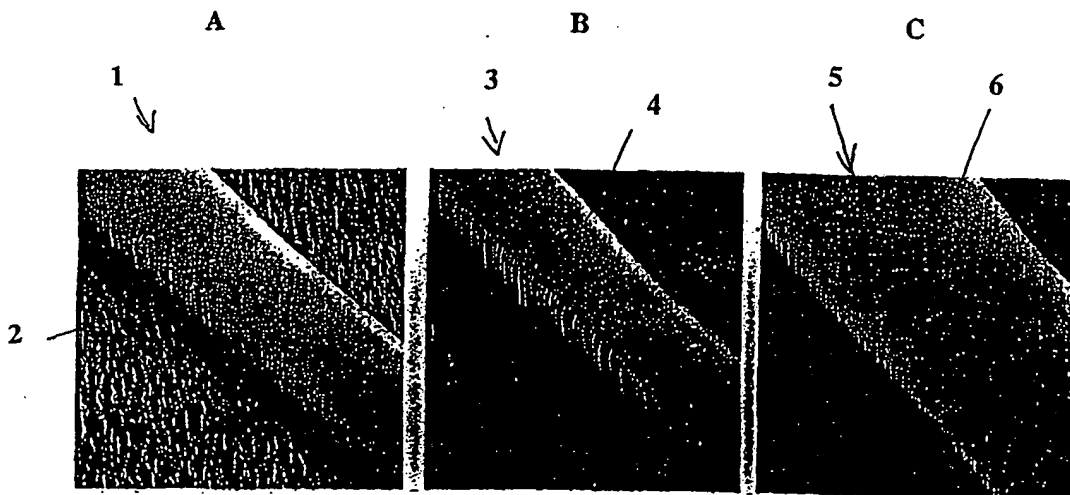
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(54) Title: A REACTIVE ION ETCHING PROCESS



(57) Abstract

A reactive ion etching process controls the flow rate of at least one etchant gas used in said reactive ion etching process, the pressure of said at least one etchant gas; and the r.f. power used in said reactive ion etching process. The parameters of flow rate, pressure and r.f. power are selected to obtain a desired etch rate and/or a desired level of material re-deposition in the reactive ion etching process.

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1
2 A REACTIVE ION ETCHING PROCESS
3

4 FIELD OF THE INVENTION
5

6 The invention relates to a reactive ion etching (RIE)
7 process, in particular to a RIE process which can be
8 used in the fabrication of an optical waveguide with
9 low surface and sidewall roughness and which has low
10 levels of material re-deposition.
11

12 BACKGROUND OF THE INVENTION
13

14 There is an increasing demand in industries such as
15 telecommunications and bioelectronics for planar
16 lightwave circuit components. Such components include
17 large scale silica glass film waveguides whose planar
18 dimensions are normally in the range $4\mu\text{m}$ to $8\mu\text{m}$ but
19 which can exceed $10\mu\text{m}$. This differs from devices which
20 are fabricated for the semiconductor industry, where
21 etch depths are small ($<2\mu\text{m}$) and where the amount of
22 etched material is typically less than 5%, such that
23 the "loading effect", or amount of material
24 redeposition, is reduced. The deep etching of the
25 silica glass films during the fabrication of such

1 waveguides by dry etch mask techniques has several
2 known disadvantages.

3
4 Large scale silica waveguides can alternatively be
5 fabricated using a combination of flame hydrolysis
6 deposition (FHD) and RIE processes. It is desirable
7 for the RIE process to have a high FHD glass etch rate,
8 high mask selectivity and to cause minimal damage to
9 the waveguide core side walls during the etching
10 process.

11
12 RIE processes have several disadvantages known in the
13 prior art. RIE generally depends on ion assisted
14 chemical reactions forming volatile species which are
15 subsequently removed during the waveguide fabrication
16 process. However, it is desirable in certain
17 applications for the waveguides to be doped with rare
18 earth or heavy metal species which form involatile
19 products during the RIE process. These involatile
20 products enable surface imperfections or "grass" to
21 develop on the etched surfaces surrounding the
22 waveguide.

23
24 By combining the RIE and FHD processes, it is possible
25 to fabricate rare earth channel waveguides with
26 relatively smooth etched surfaces. In particular, the
27 RIE process can be controlled so that certain
28 parameters directly or indirectly affect the etchant
29 speed and the amount of ion re-deposition which occurs
30 during the RIE processing stage of fabricating an
31 optical waveguide.

32
33 In particular, in the deep etching of flame hydrolysis
34 deposited silica glass, for example when 4 μm or more
35 of material is to be removed, it is highly desirable to
36 achieve a fast etch speed. A problem arises in that

1 such fast etch speeds are known in the prior art to
2 affect the integrity of the mask used to define the
3 waveguide core area. Moreover, fast etch speeds often
4 result in damage to the etched side walls of the
5 waveguide.

6

7 The invention seeks to provide an RIE process which
8 achieves a fast etch speed which preserves the
9 integrity of the mask used to define the waveguide core
10 area and which also provides high quality waveguide
11 core side walls. It is known that the choice of etchant
12 gas, which may be a mixture of actively etching gas(es)
13 with dilutant or process gas(es), can accelerate the
14 rate at which material is etched but may at the same
15 time exacerbate the amount the etchant gas undercuts
16 the mask.

17

18 Suitable ranges of values for the RIE process
19 parameters are provided according to the invention to
20 enable the RIE process to produce heavy metal or rare
21 earth doped channel waveguides. The waveguide cores
22 are formed with a desirably low level of surface
23 roughness and are etched at a desirable speed with
24 minimal damage to the waveguide side walls. A range of
25 values for the pressure of an etchant gas, the rate at
26 which the etchant gas is supplied, and the radio
27 frequency (r.f) power density used in the RIE process
28 are given.

29

30 SUMMARY OF THE INVENTION

31

32 In accordance with the invention, there is provided a
33 reactive ion etching process comprising the steps of:
34 controlling the flow rate of at least one etchant
35 gas used in said reactive ion etching process;
36 controlling the pressure of said at least one

1 etchant gas; and
2 controlling the r.f. power density used in said
3 reactive ion etching process, wherein the parameters of
4 flow rate, pressure and r.f. power are selected to
5 obtain a desired etch rate and/or to reduce the level
6 of ion dopant material redeposited in the reactive ion
7 etching process.

8
9 DESCRIPTION OF THE DRAWINGS

10
11 Embodiments of the present invention will now be
12 described, by way of example only, with reference to
13 the accompanying drawings, in which:-

14
15 Figs. 1A to 1C show scanned electron micrographs of a
16 erbium doped phosphosilicate waveguide with varying
17 levels of surface roughness.

18
19
20 DETAILED DESCRIPTION OF THE INVENTION

21
22 Referring now to the drawings, Figs. 1A to 1C illustrate
23 scanned electron microscope images of erbium doped
24 phosphosilicate waveguides formed by a method of
25 fabricating an optical waveguide which incorporates the
26 method of optimising the reactive ion etching (RIE)
27 process to achieve a desired etch rate and/or level of
28 etched surface roughness.

29
30 Referring now to Fig. 1A, an optical waveguide 1 is
31 shown which displays a moderate number of surface
32 defects 2. The RIE process in the fabrication of the
33 optical waveguide has been controlled to ensure a rapid
34 etch rate to the detriment of the smoothness of the
35 waveguide surface.
36

1 Referring now to Fig. 1B, an optical waveguide 3 is
2 shown which displays a fewer surface defects 4, than
3 shown in Fig. 1A. The RIE process in the fabrication
4 of the optical waveguide has been controlled to
5 slightly compromise the rapidity of the etch rate to
6 give a lower degree of roughness of the waveguide
7 surface.

8

9 Referring now to Fig. 1C, an optical waveguide 5 is
10 shown which displays a minimal number of surface
11 defects 6. The RIE process in the fabrication of the
12 optical waveguide has been controlled to ensure the
13 roughness of the waveguide surface is been reduced to a
14 minimum to the detriment of the etch rate.

15

16 In a preferred embodiment of the invention, a method of
17 fabricating an optical waveguide includes the following
18 stages:-

19

20 (1) Forming at least one intermediate layer on an
21 underlying substrate and optionally doping said
22 layer;

23

24 (2) Forming at least one core layer on the underlying
25 intermediate layer and optionally doping said core
26 layer;

27

28 (3) Forming a waveguide core from the core layer(s) by
29 masking the uppermost said core layer and by using
30 a reactive ion etching (RIE) process to remove the
31 unwanted portions of said core layer(s).

32

33 (4) Forming at least one cladding layer to embed the
34 waveguide core and optionally doping said cladding
35 layer.

36

1 In the preferred embodiment, any suitably appropriate
2 process can be used to perform each of stages one, two
3 and four. The masking step of stage three can be
4 performed conventionally but the reactive ion etching
5 process step of stage three is performed according to
6 the invention.

7
8 The preferred embodiment will now be described in more
9 detail. An intermediate layer, for example a buffer
10 layer and an upper intermediate layer deposited
11 thereon, is deposited on a substrate, for example a
12 silicon substrate using, for example, a flame
13 hydrolysis deposition (FHD) process.

14
15 The buffer layer comprises silica, but can be any
16 thermally oxidised layer of the substrate. The upper
17 intermediate layer comprises silica, and is doped with
18 selected dopant ions which induce certain desired
19 properties in the upper intermediate layer. The upper
20 intermediate layer is then consolidated, for example,
21 in an electrical furnace or by an FHD burner, before
22 any subsequent layers are deposited.

23
24 In the method of fabricating the optical waveguide,
25 after the upper intermediate layer is consolidated, a
26 core layer is subsequently deposited using an FHD
27 process. The core layer comprises silica, and is doped
28 with dopant ions which induce certain desired
29 properties in the core layer. The core layer is then
30 consolidated, for example in an electrical furnace or
31 by an FHD burner, at least partially before any
32 subsequent layers are deposited.

33
34 The normal FHD apparatus is modified so that the core
35 layer can be aerosol doped. An additional feed is
36 provided on the FHD apparatus supplies aerosol droplets

1 of the dopant ions. High concentrations of core layer
2 dopant ions, for example concentrations exceeding
3 0.5wt%, but more typically in the range 0.2wt% to 2
4 wt%, of rare earth ions or heavy metal ions can be
5 introduced during the deposition of the core layers by
6 using such an aerosol doping technique.

7
8 The waveguide core is then formed from the core layer
9 by masking the core layer and etching away the unwanted
10 portion of the core layer. Subsequently, another
11 cladding layer is deposited and consolidated similarly
12 to the first cladding layer.

13
14 Many variations in the stages of fabricating an optical
15 waveguide are possible which differ from those
16 described in the preferred embodiment. For example,
17 more than one intermediate, core and/or cladding layers
18 can be deposited at each stage. The intermediate, core
19 and cladding layers may be only partially consolidated
20 after they are deposited and full consolidation can be
21 achieved by subsequent thermal treatment, for example,
22 when a subsequently deposited layer is being
23 consolidated. Obviously, the choice of fabrication
24 process depends to an extent on the deposition and
25 consolidation temperatures of each layer.

26
27 The waveguide core is formed from the core layers by
28 performing a suitable masking process on the uppermost
29 core layer so that a mask portion covers the waveguide
30 area to be retained during the RIE process. The RIE
31 process parameters are selected to enable the desired
32 etch rate to be achieved with a minimal amount of
33 erosion of the mask portion and with a minimal amount
34 of undercut under the mask portion. The RIE etchant
35 gas is thus selected to exhibit a high degree of
36 selectivity between the mask layer and the waveguide

1 layers to be etched.

2

3 The mask used is preferably metal, for example,
4 nichrome (NiCr) or alternatively is Ni, Ti:Ni, or
5 Ti:NiCr. Other suitable masks include amorphous
6 silicon and polysilicon. The mask is formed by
7 depositing a mask layer, i.e. a layer of masking
8 material, on the uppermost core layer. The metal masks
9 may be deposited, for example, by thermal evaporation,
10 electron beam evaporation or sputtering. Amorphous
11 silicon masks may be deposited, for example, by plasma
12 enhanced chemical vapour deposition (PECVD), and
13 silicon masks may be deposited, for example, by low
14 pressure chemical vapour deposition (LPCVD).

15

16 A layer of resist, for example, photo-resist, is then
17 formed on top of the mask layer and is patterned using
18 standard photo-lithographic techniques which remove the
19 resist. The exposed unwanted mask areas are then
20 etched away and the wanted mask portion defining the
21 waveguide is finally left covered by the mask and
22 resist layers.

23

24 Preferably, the metal mask is deposited by using an
25 evaporator. To prevent mask erosion during the etchant
26 process, a mask thickness of 100 nm was used which lies
27 in a suitable range of 10nm to 800nm. A suitable
28 photoresist is SHIPLEY™ S1818 which was postbaked at
29 120°C. Alternatively, a 1.8µm thick photoresist can
30 be alone as a dry etch mask.

31

32 To achieve the desired etch rates and waveguide wall
33 surface roughness, the method of controlling the RIE
34 process selectively controls certain selected
35 parameters, for example, the pressures of the etchant
36 gases used, the flow rate of the etchant gas, and the

1 r.f. power density used. It is desirable for the
2 etchant gas to offer a high etch rate yet be highly
3 selective between the mask and core material. If the
4 selectivity is low, the side wall quality is reduced.

5
6 The etchant gas is ideally a fluorine based etch gas
7 and/or at least one other gas, for example, a dilutant
8 or a process gas, e.g. O_2 . Fluorine based gases can be
9 used, for example, to etch both metal and silicon based
10 masks or alternatively, chlorine bases gases can be
11 used to etch silicon based masks. The process gas is
12 selected, for example, so that the amount of polymer
13 formation during the RIE process stage of fabricating a
14 waveguide is increased, which increases the anisotropy
15 of the etching process and so improves the vertical
16 orientation of the side-walls of the waveguide channel
17 which are etched.

18
19 These selected RIE parameters affect the etch rate of
20 the RIE process and the amount of material which is
21 redeposited during the RIE processing stage. The
22 amount of re-deposition which occurs during the RIE
23 processing stage directly and/or indirectly determines
24 the level of surface roughness of the etched surfaces
25 formed.

26
27 In the preferred embodiment, the etchant gas includes a
28 process gas, for example O_2 , and a fluorine based
29 chemical, for example, CHF_3 . Selecting suitable values
30 for the RIE parameters with this etchant gas enables
31 the RIE process to form waveguide cores which possess a
32 desirably low level of surface roughness and/or which
33 are formed at a desirable etch rate. The parameters
34 varied are the fluorine based etchant gas flow rate,
35 the process gas flow rate, the etchant gas pressure and
36 the r.f. power density. Selected values of these RIE

1 parameters and the RIE etchant speeds and levels of
2 waveguide core surface roughness obtained by the RIE
3 process using these parameters are detailed in Table 1A
4 shown overleaf.

5

6 A level setting for the RIE process combines selected
7 values of the RIE parameters. Three level settings are
8 given in Table 1B shown below:-

9

Level Settings	CH ₃ Flow Rate (sccm)	O ₂ Flow rate (sccm)	Etch Pressure (mTorr)	Rf Power (W/cm ²)
1	5	0	20	0.16
2	20	5	60	0.38
3	45	10	100	0.6

10

11

12

13

14

15

16 Table 1B The values set for each of the RIE parameters
17 for each level setting of the RIE process.

18

19 The etch rate average for an CHF₃ flow of 5 sccm (runs
20 1,2, and 3) is given by the average of E1 (1.85 μ m/hr),
21 E2 (5.42 μ m/hr) and E3 (13.11 μ m/hr). This is denoted as
22 E_{C1}, and is 6.79 μ m/hr. Similarly, the etch rate average
23 for CHF₃ flow setting 2, 25 sccm, is given by the

Selected Values of parameters governing the RIE process					Resultant Features of the RIE process		
Run Number	CHF ₃ Flow Rate (sccm)	O ₂ Flow Rate (sccm)	Etch Pressure (mTorr)	RF Power Density (W/cm ²)	Etch Rate (μm/hr)	Roughness (nm)	
1	5	0	20	0.16	E1	1.85	R1
2	5	5	60	0.38	E2	5.42	R2
3	5	10	100	0.6	E3	13.11	R3
4	25	0	60	0.6	E4	7.62	R4
5	25	5	100	0.16	E5	1.84	R5
6	25	10	20	0.38	E6	3.02	R6
7	45	0	100	0.38	E7	4.68	R7
8	45	5	20	0.6	E8	6.02	R8
9	45	10	60	0.16	E9	3.00	R9

Table 1 The CHF₃ gas flow rate, the O₂ gas flow rate, etchant gas pressure and r.f. power density and the resulting etch rate of the RIE process and the roughness of the waveguide surface etched by the RIE process.

1 average of the etch rates of experiments 4, 5 and 6 and
2 is $4.16 \mu\text{m/hr}$. The etch rate average for CHF_3 flow level
3 setting 3 is $E_{C3} = 4.57 \mu\text{m/hr}$.

4

5 The average etch rates obtained by the RIE process for
6 each level setting of the RIE process are shown
7 overleaf in Table 2A, and the average surface roughness
8 of the waveguides formed by each level setting are
9 shown in Table 2B.

10

11 Each of the first three rows in Table 2A corresponds to
12 a different level setting, i.e., to a different set of
13 parameters selected to control the RIE process. The
14 final row gives the difference between the maximum and
15 minimum etch rates in each column.

16

17 In table 2A, the etch rate difference for the CHF_3 flow
18 parameter values selected, ΔE_c , is $E_{C1} - E_{C2}$, or 2.63
19 $\mu\text{m/hr}$. Similarly, the etch rate difference for the
20 pressure parameter values selected is given by $E_{Pr3} -$
21 E_{Pr1} , or $2.91 \mu\text{m/hr}$.

22

23 The maximum etch rate for each of the RIE parameter
24 values selected occurs at the smallest CHF_3 flow value,
25 greatest O_2 flow value, highest pressure value and
26 highest power value, i.e., by the values E_{C1} , E_{O3} , E_{Pr3} ,
27 E_{Po3} . The RIE process is optimized for maximum etch rate
28 by setting the RIE parameters to these values.

29

30 Table 2B shows the average surface roughness of the
31 optical waveguide formed by the RIE process. Each of
32 the first three rows corresponds to a different level
33 setting: i.e., to a different set of parameters
34 selected to control the RIE process. The final row
35 gives the difference between the maximum and minimum
36 surface roughness obtained in each column.

Average Glass Etch Rate ($\mu\text{m/hr}$)						
Level	CHF ₃		O ₂		Pressure	Power Density
1	E _{C1}	6.79	E _{O1}	4.72	E _{Pr1}	E _{Po1}
2	E _{C2}	4.16	E _{O2}	4.43	E _{Pr2}	E _{Po2}
3	E _{C3}	4.57	E _{O3}	6.38	E _{Pr3}	E _{Po3}
Max.Diff.	ΔE_C	2.63	ΔE_O	1.95	ΔE_{Pr}	ΔE_{Po}
					2.91	6.69

Table 2A

Roughness (nm)						
Level	CHF ₃		O ₂		Pressure	Power Density
1	R _{C1}	72.50	R _{O1}	70.80	R _{Pr1}	R _{Po1}
2	R _{C2}	56.23	R _{O2}	29.20	R _{Pr2}	R _{Po2}
3	R _{C3}	40.07	R _{O3}	68.80	R _{Pr3}	R _{Po3}
Max. Diff.	ΔR_C	32.43	ΔR_O	41.60	ΔR_{Pr}	ΔR_{Po}
					61.13	79.73

Table 2B

1 Table 2B shows that RIE process produces minimal
2 roughness for the greatest CHF_3 flow, medium O_2 flow,
3 smallest pressure and smallest power (E_{C_3} , E_{O_2} , E_{Pr_1} ,
4 E_{Po_1}).

5
6 The following settings for the RIE parameters: a CHF_3
7 flow rate of 25 sccm, an O_2 flow rate of 5 sccm, a
8 pressure of 20 mTorr, and a r.f. power density of
9 $0.6\text{W}/\text{cm}^2$ give an etch rate of $5.2\text{ }\mu\text{m}/\text{hr}$. These
10 settings give a desirably low level of re-deposition
11 and a desirably low level of surface roughness. Fig.
12 1C displays a scanned electron microscope image of an
13 erbium doped phosphosilicate waveguide 5 fabricated
14 using these RIE parameter values.

15
16 To achieve a desirably smooth waveguide surface the
17 following ranges of RIE parameter values are suitable:
18 a CHF_3 flow rate of 5 to 75 sccm; an O_2 flow rate of 0
19 to 15 sccm, a pressure of 5 to 30 mTorr, and a r.f.
20 power density of 0.06 to 0.64 Wcm^{-2} . The selection of
21 parameter values in these ranges gives RIE etch rates
22 of between 1.8 and $1.3\text{ }\mu\text{m}/\text{hr}$ and surface roughness
23 levels of between 5 and 100 nm.

24
25 In another embodiment, the RIE process is controlled to
26 give an optimum etch rate which depends strongly on the
27 pressure and power by selecting the following parameter
28 values: a CHF_3 carrier gas flow rate of 45 sccm, an O_2
29 flow rate of 5 sccm, a pressure of 20 mTorr, and a r.f.
30 power density of 0.6 Wcm^{-2} . Fig. 1B illustrates a
31 scanned electron microscope image of an erbium doped
32 phosphosilicate waveguide 5 formed according to this
33 embodiment.

34
35 To achieve a desirably high etch rate the following
36 ranges of parameter values are suitable: a CHF_3 flow

1 rate of 5 to 45 sccm; an O₂ flow rate of 5 to 15 sccm, a
2 pressure of 80 to 120 mTorr, and a r.f. power density
3 of 0.54 to 0.95 W/cm². The selection of parameter
4 values in these ranges gives RIE etch rates of between
5 8 μm and 13 μm/hr and surface roughness levels of between
6 100 and 200 nm.

7

8 Although O₂ and CHF₃ form the etchant gas used in the
9 RIE process in the preferred embodiment of the
10 invention, other fluoride based etchant gases can be
11 used for etching silica type material such as CF₄, C₂F₆,
12 SF₆, etc. Process gases such as Ar, CH₄, etc can also
13 be incorporated into the etchant. The RIE processing
14 stage can be generally tailored for each etchant gas
15 mix to produce optimal etch rates by using high flow
16 rate, low pressure and high power parameters.

17

18 Alternatively, the RIE processing stage can be tailored
19 to reduce the amount of ion deposition and thus the
20 level of surface roughness of the optical waveguide
21 formed by the method. Desirably low levels of surface
22 roughness of silicon based waveguides of between 5 nm
23 to 100 nm can be achieved.

24

25 Waveguides which are fabricated using the invention
26 display further desired properties, for example
27 substantially vertical (90°) sidewalls.

28

29 By the selection of appropriate values for the pressure
30 and flow rates of the etchant gases, the RIE rate can
31 exceed 115 nm/min. An etch rate in excess of 115
32 nm/min was achieved using an etchant gas flow rate of
33 ~45 sccm, a low etchant gas pressure of ~20 mTorr and by
34 using a high r.f. power density of 0.6 Wcm⁻². The
35 resulting waveguide has a side wall anisotropy of >89°
36 and a relatively low surface roughness of 19 nm.

1 While several embodiments of the present invention have
2 been described and illustrated, it will be apparent to
3 those skilled in the art once given this disclosure
4 that various modifications, changes, improvements and
5 variations may be made without departing from the
6 spirit or scope of this invention.

7
8 The text of the accompanying claims and abstract are
9 hereby declared to be incorporated into the text of the
10 description.

1 Claims:-

2

3 1. A reactive ion etching (RIE) process comprising
4 the steps of:

5 controlling the flow rate of at least one etchant
6 gas used in said reactive ion etching process;

7 controlling the pressure of said at least one
8 etchant gas; and

9 controlling the r.f. power density used in said
10 reactive ion etching process, wherein the parameters of
11 flow rate, pressure and r.f. power density are selected
12 to obtain a desired etch rate and/or a desired level of
13 material re-deposition in the reactive ion etching
14 process.

15

16 2. A RIE process as claimed in Claim 1, wherein the
17 etchant gas comprises a first etchant gas and at least
18 one other etchant gas and/or process gas.

19

20 3. A RIE process as claimed in either Claim 1 or
21 Claim 2, wherein the flow rate of the first etchant gas
22 is controlled such that its parameter ranges from 5
23 sccm to 45 sccm.

24

25 4. A RIE process as claimed in any either Claim 2 or
26 Claim 3, wherein the etchant gas further includes a
27 process gas whose flow rate is controlled such that its
28 parameter ranges from 0 sccm to 10 sccm.

29

30 5. A RIE process as claimed in any preceding claim,
31 wherein the pressure of the etchant gas is controlled
32 such that its parameter ranges from 20 mTorr to 100
33 mTorr.

34

35 6. A RIE process as claimed in any preceding claim,
36 wherein the r.f. power density is controlled such that

1 its parameter ranges from 0.16 Wcm^{-2} to 0.6 Wcm^{-2} .

2

3 7. A RIE process as claimed in any preceding claim,
4 wherein the etchant gas is a fluorine based gas.

5

6 8. A RIE process as claimed in Claim 7, wherein the
7 fluorine based gas is CHF_3 and/or C_2F_6 and/or SF_6 and/or
8 CF_4 and/or CBrF_5 .

9

10 9. A RIE process as claimed in any of claims 2 to 8,
11 wherein the said process gas is O_2 , and/or Ar, and/or
12 CH_3 , and/or CH_4 , and/or C_2H_4 .

13

14 10. A RIE process as claimed in any one of claims 2 to
15 9, wherein the first etchant gas flow rate ranges from
16 5 sccm to 75 sccm; the process gas flow rate ranges
17 from 0 sccm to 15 sccm; the etchant gas pressure ranges
18 from 5 mTorr to 30 mTorr; and the r.f. power density
19 ranges from 0.06 Wcm^{-2} to 0.64 Wcm^{-2} .

20

21 11. A RIE process as claimed in any preceding claim,
22 wherein the etchant rate of the RIE process is greater
23 than 115 nm/min.

24

25 12. A RIE process as claimed in any one of claims 2 to
26 9, wherein the first etchant gas flow rate ranges from
27 5 sccm to 45 sccm; the second process gas flow rate
28 ranges from 5 sccm to 15 sccm; the etchant gas pressure
29 ranges from 80 mTorr to 120 mTorr; and the r.f. power
30 density ranges from 0.54 Wcm^{-2} to 0.95 Wcm^{-2} .

31

32 13. A method of fabricating a waveguide comprising the
33 steps of:

34 forming an intermediate layer upon a substrate;
35 forming a core layer on the intermediate layer;
36 forming a waveguide core from the core layer; and

1 forming a cladding layer to embed the waveguide
2 core;

3 wherein the step of forming the waveguide core
4 comprises the steps of:

5 forming a mask on the core layer; and

6 removing an unwanted portion of the core layer
7 leaving the waveguide core using a reactive ion etching
8 process as claimed in any preceding claim.

9

10 14. A method of fabricating a waveguide as claimed in
11 claim 13, wherein the RIE process etches material to a
12 depth greater than 4 μm .

13

14 15. A method of fabricating a waveguide as claimed in
15 either Claim 13 or Claim 14, wherein the RIE process
16 fabricates a waveguide core with a planar dimension
17 greater than 20 μm .

18

19 16. A method of fabricating a waveguide as claimed in
20 any of Claims 13 to 15, wherein the etched surfaces of
21 the waveguide core have a surface roughness of 5 nm to
22 100nm.

23

24 17. A method of fabricating a waveguide as claimed in
25 any of claims 13 to 16, wherein the RIE etchant and/or
26 process gas is selected to optimise the selectivity
27 between the mask and the core layer; and the range of
28 values for the RIE parameters are selected accordingly.

29

30 18. A method of fabricating a waveguide as claimed in
31 claim 14, wherein the RIE process etches material to a
32 depth greater than 10 μm .

33

34 19. A method of fabricating a waveguide as claimed in
35 any of Claims 13 to 18 wherein the mask used is formed
36 by depositing a layer of Ni, Ti:Ni, Ti:NiCr, amorphous

1 silicon and/or polysilicon.

2

3 20. A method of fabricating a waveguide as claimed in
4 claim 19, wherein the mask layer is formed by either
5 thermal evaporation, or electron beam evaporation, or
6 sputtering, or plasma enhanced chemical vapour
7 deposition, or low pressure chemical vapour deposition.

8

9 21. A method of fabricating a waveguide as claimed in
10 any of Claims 13 to 20, wherein at least one layer of
11 the waveguide is doped with rare earth ions.

12

13 22. A method of fabricating a waveguide as claimed in
14 claim 21, wherein the dopant concentration of the rare
15 earth ions is substantially greater than or equal to
16 0.5 wt%.

17

18 23. A method of fabricating a waveguide as claimed in
19 any of Claims 13 to 22, wherein the amount of polymer
20 formation undergone by the etchant gas during the
21 reactive ion etching process increases the anisotropy
22 of the etching process such that substantially vertical
23 waveguide side-walls are etched by the etching process.

24

25 24. A reactive ion etching process substantially as
26 described herein and with reference to the accompanying
27 drawings.

28

29 25. A method of fabricating a waveguide substantially
30 as described herein and with reference to the
31 accompanying drawings.

32

33

34

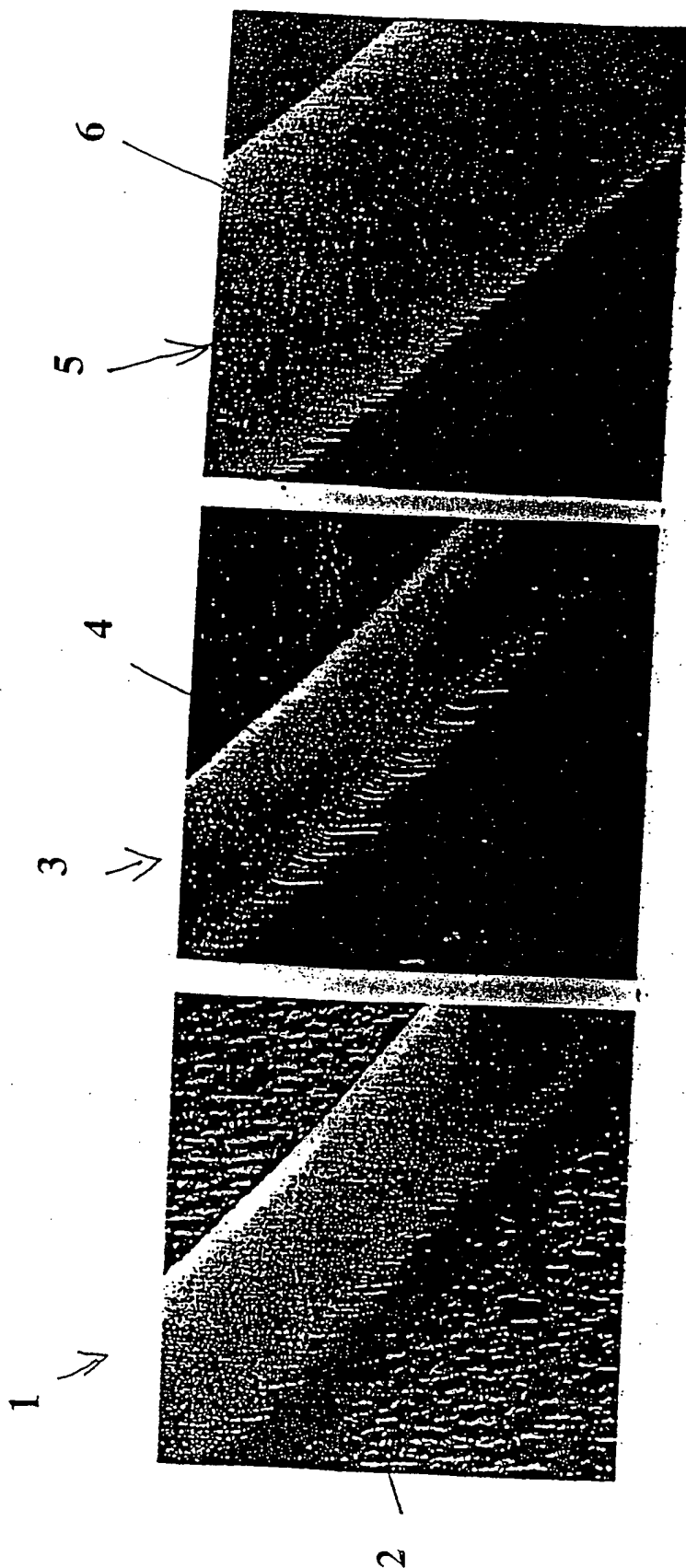


FIG. 1A

FIG. 1B

FIG. 1C

INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 00/01231

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01L21/311 G02B6/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 H01L G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, INSPEC, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 176 790 A (ARLEO ET AL.) 5 January 1993 (1993-01-05) examples	1-5, 7-9, 11
Y	—	13-15, 21
Y	BONAR J ET AL: "AEROSOL DOPED ND PLANAR SILICA WAVEGUIDE LASER" ELECTRONICS LETTERS, GB, IEE STEVENAGE, vol. 31, no. 2, 19 January 1995 (1995-01-19), pages 99-100, XP000504787 ISSN: 0013-5194 abstract	13-15, 21
	— -/-	

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents:

- *A* document defining the general state of the art which is not considered to be of particular relevance
- *E* earlier document but published on or after the international filing date
- *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- *O* document referring to an oral disclosure, use, exhibition or other means
- *P* document published prior to the international filing date but later than the priority date claimed

- *T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- *X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- *Z* document member of the same patent family

Date of the actual completion of the international search

16 August 2000

Date of mailing of the international search report

03.09.00

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INTERNATIONAL SEARCH REPORT

In International Application No

PCT/GB 00/01231

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	<p>BONDUR J A ET AL: "GAS MIXING TO PREVENT POLYMER FORMATION DURING REACTIVE ION ETCHING"</p> <p>IBM TECHNICAL DISCLOSURE BULLETIN, US, IBM CORP. NEW YORK,</p> <p>vol. 21, no. 10,</p> <p>1 March 1979 (1979-03-01), page 4016</p> <p>XP002003416</p> <p>ISSN: 0018-8689</p> <p>the whole document</p>	1-8,10
A	<p>DATABASE INSPEC 'Online!</p> <p>INSTITUTE OF ELECTRICAL ENGINEERS, STEVENAGE, GB;</p> <p>Inspec No. AN5359690,</p> <p>DUTTA: "Prospects of vertical and smooth etching of thick silicon oxide for opto-electronics integration"</p> <p>XP002145015</p> <p>abstract</p>	1,13
A	<p>EP 0 763 850 A (APPLIED MATERIALS)</p> <p>19 March 1997 (1997-03-19)</p> <p>abstract</p>	1-12
A	<p>US 5 431 772 A (BABIE ET AL.)</p> <p>11 July 1995 (1995-07-11)</p> <p>abstract</p>	1-12

INTERNATIONAL SEARCH REPORT

International application No.
PCT/GB 00/01231

Box I Observations where certain claims were found unsearchable (Continuation of Item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☒ Claims Nos.: 24,25
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:
Claims 24 and 25 do not meet the requirements of Rule 6.2(a).

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of Item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
- ☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Continuation of Box I.2

Claims Nos.: 24,25

Claims 24 and 25 do not meet the requirements of Rule 6.2(a).

The applicant's attention is drawn to the fact that claims, or parts of claims, relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/GB 00/01231

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5176790 A	05-01-1993	NONE	
EP 763850 A	19-03-1997	US 5935877 A JP 9148314 A	10-08-1999 06-06-1997
US 5431772 A	11-07-1995	US 5188704 A	23-02-1993